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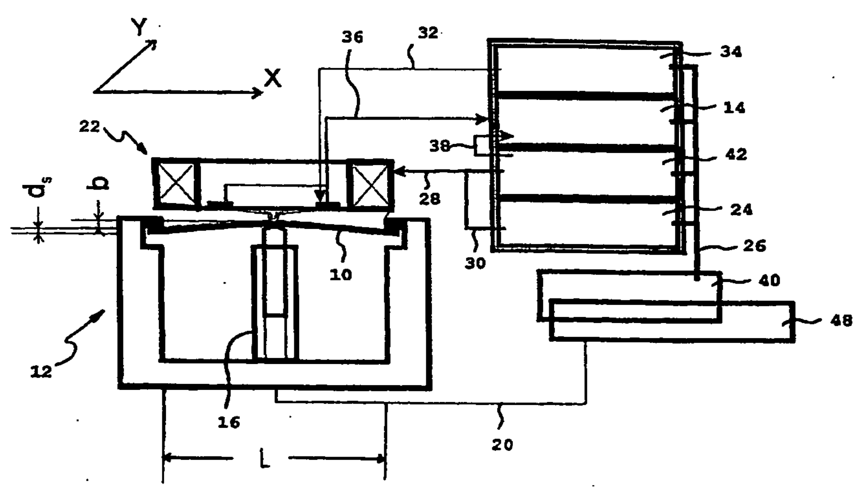
(54) Title: METHOD FOR MEASURING MAGNETOSTRICTION IN MAGNETORESISTIVE ELEMENTS



(57) Abstract: A method for directly measuring the magnetostriction constant of a magnetoresistive element is provided. The method consists of the following steps: 1) providing a substrate carrying one or more magnetoresistive elements; 2) inserting said substrate into a bending fixture; 3) applying a magnetic DC field parallel to said substrate; 4) applying a magnetic alternating field perpendicular to said substrate and parallel to the magnetoresistive layers of said elements; 5) measuring a signal from said element; 6) applying a mechanical stress parallel to said substrate by bending said substrate; and 7) changing said magnetic DC field until the signal measured before applying said mechanical stress is reached.

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DESCRIPTION

Method for Measuring Magnetostriction in Magnetoresistive Elements

Field of the Invention

The present invention relates in general to the measurement of the magnetostriction constant. More specifically, the invention relates to such measurements in magnetoresistive devices.

Background of the Invention

There are many situations in which there is a need to measure a magnetic field. Among such situations are the measurement of position or proximity of a magnetized portion of a structure, the reactant of stored magnetic information, the measurement of current flows without the need of a measuring device in the current flow path, etc.

Many of the magnetic effects in such situations are relatively small and therefore require a sensitive magnetic sensor. A magnetic sensor capable of sensing such small magnetic field perturbations, and which is economical to fabricate, is provided on the basis of the magnetoresistive effect. Such magnetoresistive material based magnetic sensors can be fabricated as thin films when using monolithic integrated circuit fabrication techniques, and so can not only be made economically but also made quite small in size.
A magnetoresistive material based magnetic sensor is arranged by providing a magnetoresistive material to be

used as an electrical resistor. A current is passed therethrough, and the voltage there across will depend on the effective resistance of the material over the path in which the current flows. That resistance value will depend in turn on the state of the magnetization of the material. If the magnetization is parallel to the current flow, what is the case for Anisotropic Magnetoresistance (AMR), the material will exhibit a maximum resistance, and it will exhibit a minimum resistance for magnetization perpendicular to the current flow.

For the Giant Magnetoresistance (GMR), the maximum resistance is for parallel alignment of the magnetization of adjacent magnetic layers, separated by non-magnetic interface layers. A spin valve system consists of two magnetic layers, a free layer and a pinned layer, the pinning can be made by an antiferromagnetic layer or by antiferromagnetically coupled pinning layers.

The current in such systems can be in plane (CIP) or perpendicular to plane (CPP). The CPP structure is normally used in tunneling devices (Tunneling Magnetoresistance - TMR), where the non-magnetic interface layer consists of an isolator.

In the magnetoresistive device there will be a free rotating layer with an effective magnetization. An external field acting on the magnetoresistive material will rotate the magnetization direction therein to change the resistance of the layer system as a result. The changed resistance carrying the current causes a voltage drop change across the resistor which can be sensed as an indication of the magnitude of the external field.

The effective resistance of such a film will vary as the

square of the cosine of the angle between the effective magnetization direction and the current flow direction through the material in the AMR case and as the cosine of the angle of adjacent layers in the GMR or TMR case. The total resistance, however, is usually not of interest but rather the change in resistance in response to a change in the applied external magnetic field. In the AMR case, this change is often best measured at a point along the squared cosine response curve where the curve approximates a linear function.

To provide operation on such a linear portion of the response curve requires that there be an initial angle between the direction of current flow and the nominal direction of magnetization in the absence of any externally applied fields. This can be accomplished in alternative ways in a bias arrangement. The magnetoresistive material can be placed on the device substrate as a continuous resistor in a „herringbone" pattern or act of continuously connected multiple inclines, with the angle of incline being approximately 45° with respect to the direction of extension of the resistor. There then must be provided a source for a magnetic bias field to be pointed in a direction which is 90° to the direction of the extension of the resistor.

Another method is to provide a linear strip of magnetoresistive material, but to add individual conductors across that strip at an angle of 45° with respect to the direction of the strip. This, in effect, causes the current to flow at an angle through the magnetoresistive strip with respect to the direction of elongation of the strip itself. This latter configuration is often called a „barber pole" sensor because of its configuration, and such an arrangement can eliminate the need for an external source of a magnetic bias field.

In magnetic recording heads the magnetization of the sensing layer of an AMR sensor is turned by 45° in relation to the sense current by the stray field of an adjacent magnetic layer magnetized perpendicular to the direction of the sensor strip. This layer can be a hard magnetic material (Hard Bias layer) or a soft magnetic material (Soft adjacent layer) magnetized by the sense current.

In GMR or TMR elements the magnetization of the free layer has to be directed parallel to the strip direction. This is normally done by a hard bias layer put on each side of the sensor. The magnetization of the pinned layers will be fixed perpendicular to the strip direction by antiferromagnetic coupling.

Magnetostriction is an essential parameter for controlling the magnetic properties of thin films and multilayers. Magnetostriction describes the change in length of a magnetic material by magnetic reversal.

In magnetic recording elements it is important to have homogeneously magnetized magnetic layers, especially the sensing layer (free layer) in the sensing layer stack. Inhomogeneously magnetized regions, like vortices or magnetic domains, cause instabilities in the recording signal. Therefore, the magnetic layers are aligned by local magnetic fields (exchange coupling field, hard bias field). Local inhomogeneities can be caused by magnetostrictive anisotropy. Therefore, the magnetostriction has to be controlled very precisely.

Various experimental methods have been developed for investigating the magnetoelastic properties of thin films. One of them is the direct measurement by the so-called „cantilever method". A change in magnetization leads to a change in length

which with thin films causes bending of the substrate. This is, e.g., described in E. du Trémolet de Lacheisserie et al., „Magnetostriction and internal stresses in thin films: the cantilever method revisited", Journal of Magnetism and Magnetic Materials 136 (1994), pp. 189-196.

Another possibility is the indirect measurement by means of the strain gauge method, which creates mechanical stresses in a magnetic film. The magnetic anisotropy changes through magnetostrictive coupling. This is, e.g., described in D. Markham et al., „Magnetostrictive measurement of magnetostriction in Permalloy", IEEE Transactions on Magnetics, vol. 25, no. 5, September 1989, pp. 4198-4200.

An apparatus for measuring the magnetostriction constant of a magnetic membrane is as well disclosed in Patent Abstracts of Japan, JP 62106382 A2.

Kenji Narita et al., IEEE Transactions on Magnetics, vol. Mag-16, no. 2, March 1980, pp. 435-439, disclose a method to measure the saturation magnetostriction of a thin amourphous ribbon by means of Small-Angle Magnetization Rotation (SAMR).

However, no method is known to measure the magnetization changes using the magnetoresistive effect of magnetic sensors directly, so that the real environment of the sensor is reflected. Therefore, there is still a need for improvement of such methods.

Summary of the Invention

It is therefore an object of the present invention to provide a method for measuring the magnetostriction constant of magnetical elements.

These and other objects and advantages are achieved by the method disclosed in claim 1.

Advantageous embodiments of the invention are disclosed in the dependent claims.

Brief Description of the Drawings

The Figure schematically depicts a setup for measuring the magnetostriction constant according to the method of the present invention.

Detailed Description of the Preferred Embodiment

In the present invention, the magnetostriction constant (MS) in Anisotropic Magnetoresistance (AMR), Giant Magnetoresistance (GMR) or Tunneling Magnetoresistance (TMR) (in general XMR) based elements, like magnetic recording heads, magnetic field sensors and the like, is measured by small angle magnetization rotation (SAMR). The electrical signal of the sensor is used to measure the magnetization rotation caused by an external field. In Magnetoresistance (MR) devices, the magnetization is biased by various methods, e.g., hard bias, antiferromagnetic exchange coupling, barber pole, etc. For the proposed M_S measurement the bias fields (hard bias, soft bias, exchange field) can be supported by an additional external DC field (HDC) which has to be aligned parallel to the applied stress. If the stress in the thin film is changed, the sensor signal will also change due to magnetostrictive coupling. However, the change of the sensor signal can be compensated by changing the external DC field. For shielded elements the external field has to be calibrated in order to reflect the influence of demagnetizing effects from the shielding layers. The stress can be applied on wafer

or row level by bending or by any other means like, e.g., temperature, piezo layer, etc.

The method according to the invention is not only applicable to magnetic recording heads but can also be used with magnetic field sensors and magnetic random access memories (MRAMs). However, for the sake of simplicity, it is explained in the following with respect to magnetic recording heads.

The Figure schematically depicts a setup for measuring the magnetostriction constant according to the method of the present invention. First of all, a row or a wafer 10 is inserted into a bending fixture, e.g., a deflection gauge 12, the row or wafer carrying XMR elements formed thereon. Next, a magnetic DC-field is applied parallel to the row or wafer 10, i.e., in the direction of the x-axis shown in the Figure. A magnetic alternating field is applied perpendicular to the row or wafer 10 and parallel to the magnetoresistive layers, i.e., in the direction of the y-axis shown in the Figure. This alternating field is preferably sinusoidal having the frequency f. A signal is measured at the magnetoresistive element, e.g., an XMR element, this signal being proportional to the amplitude of the alternating field having the frequency f. To do this in a simple way, a lock-in amplifier 14 can be used which is locked to the frequency of the alternating field. Now a mechanical stress is created in the layers of the XMR element parallel to the x- direction by bending the row or wafer 10, e.g., by means of a micrometer screw 16. The screw can be controlled electronically via line 20 by a „MicroScrew Control unit" 48. Due to the magnetoelastic interaction in the sensor layer of the XMR element, the magnetic anisotropy will change. This, in turn, will lead to a change in the amplitude of the signal that is measured at the lock-in amplifier 14. Finally, the applied magnetic DC-field in the direction of the x-axis is changed by a suitable control circuit until the

measuring signal at the lock-in amplifier again reaches the value that has been measured without having applied mechanical stress. The magnet assembly 22 above the row/wafer deflection fixture 12 is powered by an AC power supply 42 for magnetic field generation in y-direction, and a DC power supply 24 for generating the DC compensation field in x-direction via lines 28 and 30. The XMR-element is powered via line 32 by a constant current source 34. The sense output, the voltage across the XMR-resistor, is fed via line 36 into the lock-in amplifier 14, being locked to the excitation frequency 38 of the magnetic AC field, as already mentioned above. The whole measurement assembly can be controlled by a computer 40 via bus 26.

The magnetostriction λ_s is defined by the following formula

$$\frac{3}{2}\lambda_s * \Delta\sigma = \frac{1}{2}\Delta H_{k,\sigma} M_s \qquad \text{(I)}$$

that means that the magnetoelastic energy density (left side of the equation) is identical to the magnetic anisotropic energy density (right side of the equation).

The change of mechanical stress anisotropy $\Delta\sigma$ is connected with the strain change $\Delta\varepsilon = \frac{\Delta l}{l}$ (the relative elongation caused by bending of the row or wafer), by Hooke's law (being restricted to homogeneous and isotropic materials).

$$\Delta\sigma_x = \frac{E}{1-\nu^2}\left(\Delta\varepsilon_x - \nu\Delta\varepsilon_y\right); \Delta\sigma_y = \frac{E}{1-\nu^2}\left(\Delta\varepsilon_y - \nu\Delta\varepsilon_x\right)$$

The voltage change $\Delta\sigma$ is calculated from the mechanical parameters of the deflection:

$$\Delta\sigma = \Delta\sigma_x - \Delta\sigma_y = \frac{E}{1-\upsilon}\left(\Delta\varepsilon_x - \Delta\varepsilon_y\right) \qquad \text{(II)}$$

The following methods can be used to obtain special mechanical parameters:

1) The strain can be calculated from the deflection (b in the Figure) by the following expression:

$$\Delta\varepsilon_x = \frac{3d_s * b}{2L^2}\left[1 - \frac{|x|}{L}\right], \qquad \text{(III)}$$

where L is the bending length (cf. the Figure), d_s is the substrate thickness (cf. the Figure), x = 0 at the center of the strain gauge, and $\Delta\varepsilon_y = 0$.

2) Measuring the surface curvature by scanning a laser beam over the sample surface. The laser is reflected from the row or wafer surfaces to a position sensitive optical device.

The strain $\Delta\varepsilon$ is determined from the deflection b or the surface curvature in 2).

The measurement of the field of anisotropy follows from the total energy

$$E = H_x M_s \cos\vartheta - H_y M_s \sin\vartheta + \frac{1}{2} H_k M_s \sin^2\vartheta + \frac{1}{2}\langle N_{demag}\rangle M_s^2 \sin^2\vartheta \qquad \text{(IV)}$$

This term includes the energy in the external fields (H_x, H_y), the uniaxial anisotropy (H_k), which is composed of the induced anisotropy and the magnetostrictive anisotropy, as well as the form anisotropy, which takes into account the distribution of the magnetization of the layer to be measured.

From the condition of equilibrium dE/d = 0 follows

$$\sin \vartheta = \frac{H_y}{H_x + H_k + \langle N_{demag} \rangle M_s} \quad \text{(V)}.$$

Given a periodic excitation field $H_y = H_{yo} \sin(\Phi t)$, the magnetization will fluctuate around a state of equilibrium. The resistance of a magnetoresistive element changes with the identical frequency.

A mechanical tension changes the anisotropic field H_k. This, in turn, causes a change in resistance and a change in amplitude of the fluctuations of the magnetization. These changes are compensated by means of the external field H_x and the original state of equilibrium is restored. The following equation applies:

$$\Delta H_{k,\sigma} = \Delta H_x \qquad \text{(VI)}$$

The calculation of λ_s is straight forward. The strain $\Delta\varepsilon$ can be calculated, e.g., from (III). The stress anisotropy $\Delta\sigma$ is then derived from (II). From (I) the magnetostriction constant can be calculated by inserting $\Delta\sigma$, $\Delta H_{k,\sigma}$ from (IV).

The saturation magnetization M_s and the elasticity constants E and ν are inserted into equation (I) as constants.

The present invention suggests to use the MR-effect of the magnetic sensors directly for the measurement of the magnetization changes. The method according to the present invention has the following advantages:

- The use of a compensation method guarantees a fix magnetization state, which avoids errors by local magnetization distributions in structured films. Bias fields, e.g., softbias in anisotropic magnetoresistive sensor (AMR), longitudinal magnetically hard fields (hardbias) or exchange fields adjacent magnetic layers do not have any effect.
- The measurement is simple and fast.
- The MR effect is very sensitive.
- The measurement can be performed in the sensor elements themselves. There is no need to have separately manufactured monitor layers.

C L A I M S

1. Method for directly measuring the magnetostriction constant of a magnetoresistive element, characterized by the following steps:

   - providing a substrate carrying one or more magnetoresistive elements;
   - inserting said substrate into a bending fixture;
   - applying a magnetic DC field parallel to said substrate;
   - applying a magnetic alternating field perpendicular to said substrate and parallel to the magnetoresistive layers of said elements;
   - measuring a signal from said element;
   - applying a mechanical stress parallel to said substrate by bending said substrate; and
   - changing said magnetic DC field until the signal measured before applying said mechanical stress is reached.

2. Method according to claim 1, wherein said substrate is a a row or a wafer.

3. Method according to claim 2, wherein said row or wafer carries a plurality of magnetoresistive elements.

4. Method according to any one of claims 1 to 3, wherein said mechanical tension is applied by a micrometer screw.

5. Method according to claim 4, wherein said micrometer screw is electronically controlled.

6. Method according to any one of the preceding claims, wherein said magnetoresistive element is an Anisotropic

Magnetoresistance (AMR)-, Giant Magnetoresistance (GMR)-or Tunneling Magnetoresistance (TMR)-based sensor.

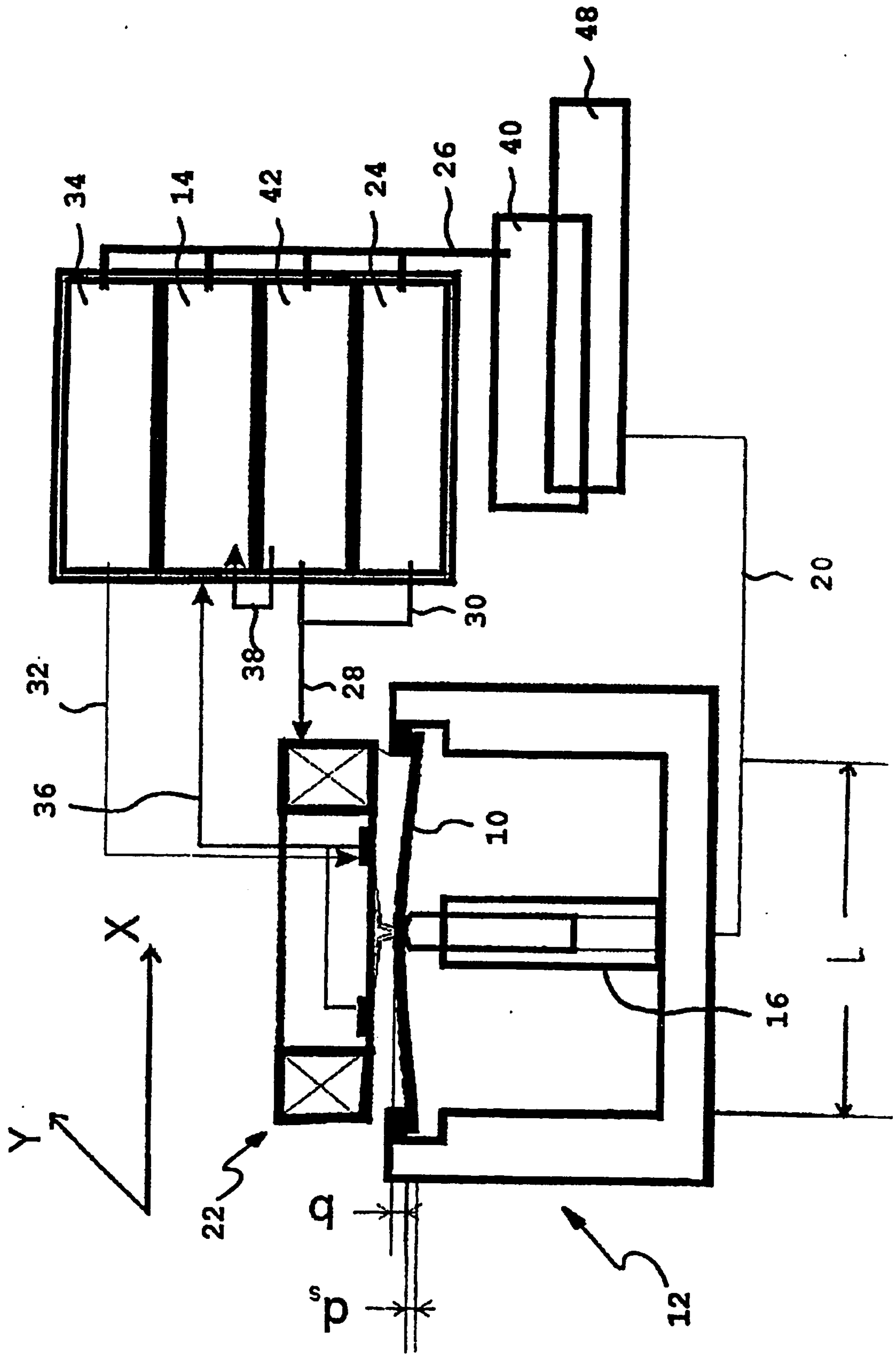

FIG. 1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 03/11512

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01R33/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, WPI Data, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BARIL L ET AL: "MAGNETOSTRICTION IN SPIN VALVES" JOURNAL OF APPLIED PHYSICS, AMERICAN INSTITUTE OF PHYSICS. NEW YORK, US, vol. 85, no. 8, PART 2A, 15 April 1999 (1999-04-15), pages 5139-5141, XP000823729 ISSN: 0021-8979 page 5139 ----- -/--	1,4,6

[X] Further documents are listed in the continuation of box C.

[ ] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 February 2004	24/02/2004

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ALI M ET AL: "Measurement of saturation magnetostriction using novel strained substrate techniques and the control of the magnetic anisotropy" JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS, ELSEVIER, AMSTERDAM, NL, vol. 202, no. 1, June 1999 (1999-06), pages 85-94, XP004363938 ISSN: 0304-8853 -----	
A	"MAGNETROSTRICTION MAPPING OF SOFT MAGNETIC FILMS ON THICK RIGID SUBSTRATES" IBM TECHNICAL DISCLOSURE BULLETIN, IBM CORP. NEW YORK, US, vol. 33, no. 8, 1991, pages 126-127, XP000107018 ISSN: 0018-8689 -----	